Evaluation of ma-N 2400 Series DUV Photoresist for Electron Beam Exposure

H. Elsner[a] and H.-G. Meyer[a], A. Voigt[b] and G. Grützner[b]

[a] IPHT Jena, Dept. of Cryoelectronics, P.O. Box 100 239, D-07702 Jena, Germany
Phone: +49-3641-65 7783, Fax: +49-3641- 65 7700, e-mail: elsner@ipht-jena.de

[b] micro resist technology GmbH, Köpenicker Str. 325, Haus 211, D-12555 Berlin, Germany
Phone: +49-30-6576 2192, Fax: +49-30-6576 2193, e-mail: microresist@snafu.de

Several DUV positive and negative tone resists were developed for the photolithography at wavelengths of 248 nm and shorter. Most of these DUV photoresists are sensitive to electron beam exposure, too.

In this paper the results of electron beam exposure of the negative tone ma-N 2400 series DUV photoresist will be presented. This resist has no chemical amplification and no critical process steps. Further, the resist provides a good resistivity to plasma etching processes, so that it can be used successfully for etch and lift-off processes.

The necessary exposure doses for the resist layers spincoated with thicknesses between 0.3 and 0.8 µm on silicon wafers were in the range between 60 and 120 µC/cm². The exposed resist was developed with the metal ion free developer MIF 726. Patterns down to the low submicrometer region were generated.

Developing properties, sensitivities and resolution of the electron beam exposed ma-N 2400 series resist tested under various conditions will be presented.

1. INTRODUCTION

Nowadays many applications require patterns with submicron dimensions. This results in the development of steppers with shorter wavelengths and an increased use of electron beam exposure systems. As a consequence suitable resists are required. Several DUV positive and negative tone resists for the photolithography at wavelengths of 248 nm and shorter were developed and thoroughly investigated[1, 2]. Most of these DUV photoresists are sensitive to electron beam exposure, too [3, 4, 5]. Nearly all of these resists operate on chemical amplification and have some critical process steps (time delay between exposure and post exposure bake, bake temperature). Negative resists for electron beam exposure with a wide process latitude and high resolution like the positive tone PMMA are not available.

In this paper the results of the electron beam exposure (variable-shaped beam, electron energy 20 keV) of the negative tone ma-N 2400 series DUV photoresist will be presented. First results presented in a previous work [6] encouraged us to further investigations of this resist series for the electron beam lithography.

2. THE EXPOSURE TOOL

We used the well established electron beam exposure system ZBA 23 H from *Leica Lithographie Systeme Jena GmbH*. This is a variable-shaped beam and vector scan system with an acceleration voltage of 20 kV. The size of the rectangular beam can be adjusted from 0.1 µm to 6.3 µm in steps of 0.1 µm in both the x- and the y-direction. The positioning of the beam takes place in work fields of 3.2 mm square and in subfields of 200 µm square with smallest steps of 100 nm. These values can be diminished by a factor of two in the high resolution mode. The laser interferometer controlled x-y stage is positioned with an accuracy of 20 nm over his travelling range of 162 mm square. The stitching accuracy of work fields is better than 150 nm. The current density can be varied from 0.4 to 3 A/cm².

3. RESIST CHARACTERIZATION

The investigated resist of the ma-N 2400 series is a negative tone DUV photoresist consisting of two components, a phenolic resin (novolak) as polymeric bonding agent and a bisazide as photoactive compound (PAC). Chemical amplification does not take place.

The resist can be developed with aqueous-alkaline developer without swelling of the resist.

4. EXPERIMENTS

We used samples with different viscosity and further samples with different amounts of the photoactive compound. The resist was spincoated on silicon wafers with thicknesses of 0.3, 0.5 and 0.8 µm, respectively. The resist coated wafers were baked at 90 °C for 3 minutes on a hotplate.

The electron exposure doses were varied in the range between 10 and 200 µC/cm². The exposed resist was developed with the metal ion free developer MIF 726. Developing time was chosen at least twice the clearing time. Standard values were 30 s, 60 s and 120 s, corresponding to the different resist thicknesses.

The exposure characteristics were measured on exposed areas of 50 µm square by a profilometer.

5. RESULTS AND DISCUSSION

We investigated the influence of the amount of the photoactive compound on the exposure characteristic of the resist. We tested samples with 0, 20, 25 and 30 weight %, respectively. The sample without PAC is pure novolak. Under the above mentioned exposure conditions novolak did not show any cross-linking reaction. This means the cross-linking of the resist is based only on the influence of the PAC and the reaction released by the exposure. The exposure sensitivity increased with increasing PAC amount. The contrast is slightly increased with increasing PAC amount (Fig. 1). The contrast has a value of about 2.8.

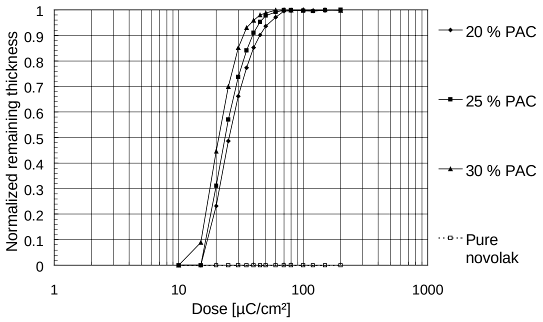

Fig. 1: Exposure characteristic of ma-N 2400 vs. PAC amount.
Resist thickness: 0.8 µm.
Development: 120 s MIF 726.

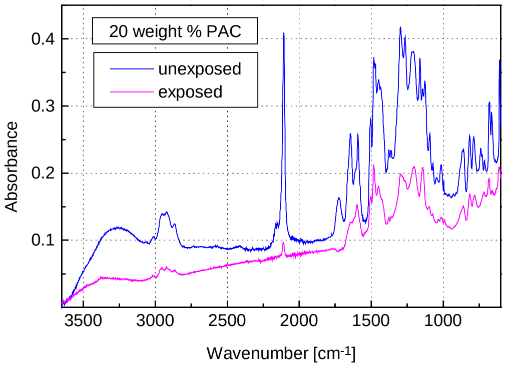

Fig. 2: IR-spectra of unexposed and exposed ma-N 2400 resist with 20 weight % PAC.

In Fig. 2 IR-spectra of unexposed and e-beam exposed (120 µC/cm²) resist with an amount of 20 weight % PAC are shown. The absorption is caused by both components, novolak and aromatic bisazide. The vibrational band at 2106 cm^{-1} represents the azido group of the PAC. At a dose of 120 µC/cm² the azido groups were almost completely (more than 90 %) bleached by the e-beam exposure. However, this PAC amount and this dose were sufficient to cross-link the novolak. In the resist with 30 weight % PAC, the PAC was bleached only to 70 % while the cross-linking was sufficient and an increased resist sensitivity was observed (Fig. 1).

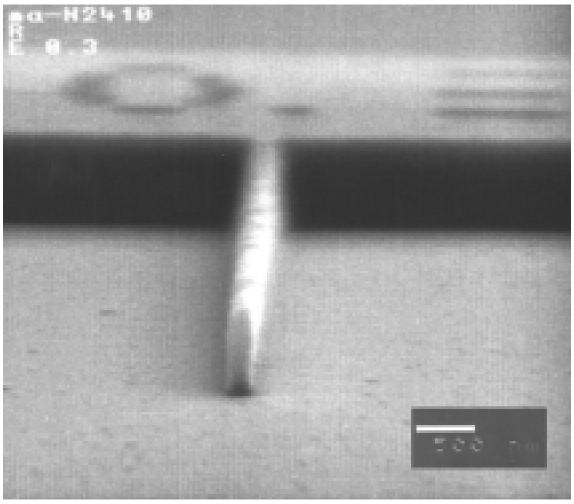

Fig. 3: ma-N 2400 single line.
Resist thickness: 0.8 µm.
Dose: 120 µC/cm².
Development: 240 s MIF 726.
Width: 0.25 µm.

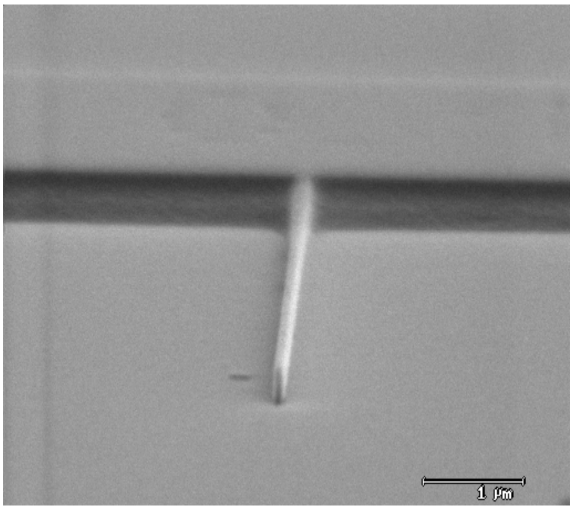

Fig. 4: ma-N 2400 single line.
Resist thickness: 0.3 µm.
Dose: 80 µC/cm².
Development: 15 s MIF 726.
Width: 0.1 µm.

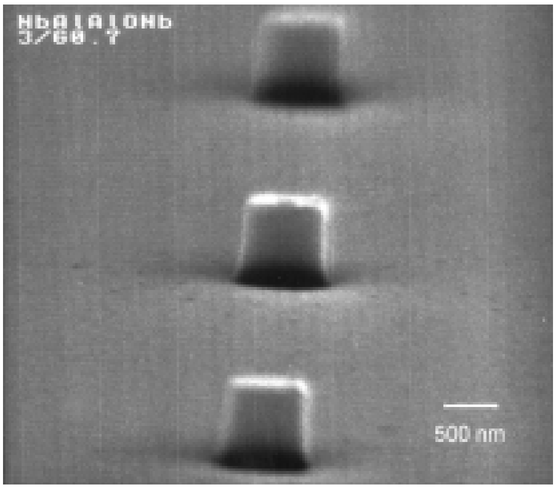

Fig. 5: ma-N 2400 dots.
Resist thickness: 0.8 µm.
Dose: 120 µC/cm².
Development: 120 s MIF 726.
Width: 0.7 µm.

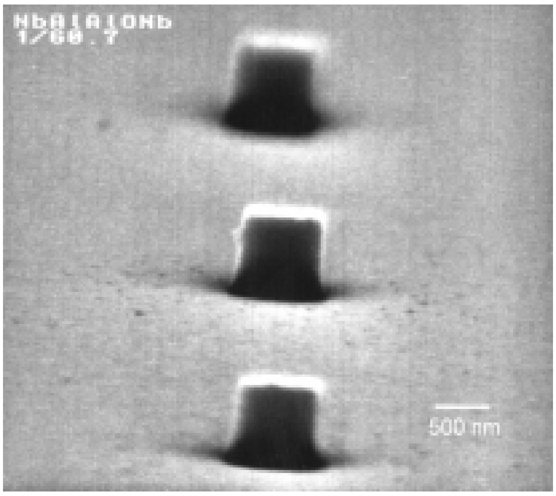

Fig. 6: ma-N 2400 dots.
Resist thickness: 0.8 µm.
Dose: 120 µC/cm².
Development: 240 s MIF 726.
Width: 0.7 µm.

The ability of the resist to generate submicrometer patterns was tested by delineating single lines in 0.8 µm and 0.3 µm thick resist, respectively. Test patterns from 1.0 µm down to 0.1 µm line widths were exposed. With a resist thickness of 0.8 µm line widths of 0.25 µm without lost of resist height were obtained (Fig. 3). With the resist film of 0.3 µm thickness the smallest exposed test pattern of 0.1 µm width were stable realised (Fig. 4). The aspect ratio of the lines is more than three.

In further investigations we hope to delineate even finer lines using film thicknesses of less than 0.3 µm. Under application of an adhesion promoter and hard bake it should be possible to generate higher aspect ratios.

At proper electron doses a prolonged developing time did not reduce the resist thickness and the width of the patterns. We exposed dot patterns of 0.7 µm width with an exposure dose of 120 µC/cm² and used developing times of 120 s and 240 s, respectively. No difference could be found in the dimensions of both samples (Fig. 5, 6). In general, the patterns have a steep side slope, but in the case of wider structures or higher doses broadening at the bottom (foot) was observed. This can be avoided by a prolonged developing time which does not influence the width at the top of the structure. The exposure characteristic shows a slightly higher contrast at this prolonged developing time (Fig. 7).

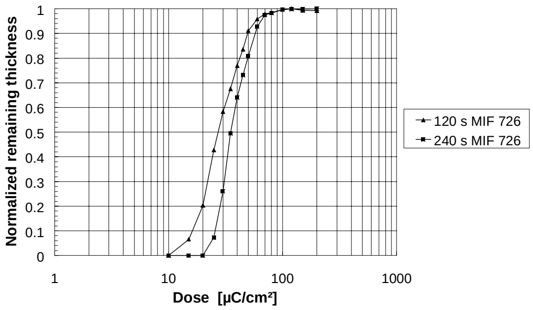

Fig. 7: Exposure characteristic of ma-N 2400 vs. development time.
Resist thickness: 0.8 µm.
PAC amount: 25 weight %.

Further, the resist has low etch rates in plasma etching processes, so that it can be successfully used for etch and lift-off processes. Application of ma-N 2400 in a reactive ion etching process with CF_4 (power 60 W) results in an etch rate of 25 nm/min., comparable with the etch rate of the underlying metal film, demonstrating a good etch selectivity.

6. CONCLUSIONS

Developing properties, sensitivity and resolution of ma-N 2400 series resist show that this resist has a wide field of application in the electron beam lithography.

The demonstrated high resolution and high process latitude, especially the absence of critical process steps like the post exposure bake (time delay, temperature) make the ma-N 2400 series resist in some cases superior to the resists with chemical amplification. The relative low sensitivity may be a handicap for high throughput applications, but brings the advantage of process simplicity.

7. ACKNOWLEDGEMENT

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